# Enhanced hazard assessment of a steep limestone rock slope above the federal road B 305

Bettina Sellmeier[1], Michael Krautblatter[1], Kurosch Thuro[1]

[1] Lehrstuhl für Ingenieurgeologie, Technische Universität München, Deutschland

## Zusammenfassung

Die Steinschlag und Felssturzereignisse der letzten Jahre, wie das Ereignis oberhalb der Gotthard Zugtrasse in Gurtnellen am 5. Juni 2012, zeigen, dass in vielen Fällen Infrastruktur, wie Straßen und Eisenbahntrassen, sowie Menschenleben betroffen sind. Um das Risiko für die Menschen und ihre Umgebung zu minimieren, ist es notwendig, die auftretenden Prozesse zu erfassen und mit Hilfe von Steinschlagsimulationen mögliche Szenarien generieren. Nach dem momentanen Stand der Dinge werden die Eingangsparameter für Steinschlagsimulationen mit Hilfe von Formblättern ermittelt, die dem jeweiligen Code angepasst sind (Dorren 2010, GEOTEST 2006). In den meisten Fällen ist es jedoch notwendig, neben den gängigen Parametern Zusatzdaten, vor allem zu den Ablösebereichen, zu erheben. Auch für die Run-Out Bereiche sind quantitative Methoden notwendig, um die Reproduzierbarkeit der Simulationen zu ermöglichen. In diesem Beitrag soll gezeigt werden, wie die Ermittlung der Eingangsparameter für Steinschlagsimulationen auf reproduzierbare und quantitative Art und Weise durchgeführt werden kann.

**Schlüsselworte**: Steinschlag Simulation, Ablösebereiche, Trennflächenanalyse

## Abstract

Rock fall hazards often affect infrastructure like railways, highways and roads, as has recently been demonstrated by the rock fall in Gurtnellen on the 5th of June, 2012, with one casualty. Associated rock fall modeling allows practitioners to analyze, assess and anticipate rockfall processes and rock fall modeling. Up to now it is common to perform rock fall analysis in 2D and 3D based on defined input parameters depending on the chosen code (Dorren 2010, GEOTEST 2006). The required parameters can be determined according to a fact sheet delivered with the manual of the program. In many cases it is not sufficient to exclusively look at the standard parameter lists, so it is required to collect enhanced data, for example parameters, which characterize the detachment process. Our study focuses on improving parameter input to numerical rock fall codes by considering the following secondary questions:

- How to prepare the input parameters in a quantitative way to obtain reproducible results?
- How can we optimize our process understanding by collecting enhanced data considering the source areas?

Our field site is located on a steep forested limestone slope that extends above the federal road B 305 near Ramsau in the Bavarian Alps, 30 km southwest of Salzburg. During the project we performed a detailed analysis of the discontinuities in the source area according to Barton & Choubey (1977) and ISRM (1978). At one key object, which is subjected to planar failure, we performed a mapping of the detachment zone including a detailed recording of the shear parameters, meaning roughness as well as the joint wall compressive strength (JCS).

In this contribution, we aim to demonstrate an effective methodology of generating reproducible geological, geotechnical and rockfall trajectory input data to yield an enhanced reconnaissance of rockfall hazards endangering vulnerable infrastructure.

**Keywords**: Rockfall simulation, source area, kinematic analysis

## 1 Introduction

Rockfall events pose a great risk for infrastructure like railways or highways as well as human life, as has been demonstrated by several events of the last years like Gurtnellen at the 5th of June in 2012 with one casualty, “Stein an der Traun” in 2010 with 2 casualties or the rockfalls at the state road SS 241 in South Tyrol in 1999 (Schweigl et al. 2003). To mitigate the rockfall risk it is advisable to improve the process understanding in terms of rockfall anticipation. This implies not only the simulation of the rockfall process itself in 2D and 3D but also the accurate recording of the input parameters. Up to now it is common to perform the determination of input parameters using fact sheets referring to the requirements of the chosen code (Dorren 2010, GEOTEST 2006), which is in many cases not sufficient. To provide an all-out process analysis it is advisable collect enhanced data, meaning an accurate consideration of the detachment mechanisms and processes. For nearly all rockfall codes the block size or the block axe are required as input parameters. To achieve realistic and reproducible estimation of the block size it is indispensable to perform a detailed geotechnical mapping of the release area as well as an analysis of the rock deposits (Mölk 2008, Evans &

HUNGR 1993). In the current project we performed a detailed parameter analysis for rockfall modeling with special regard to the source areas. This implies an accurate recording of discontinuities as well as the determination of the shear parameters according to BARTON & CHOUBEY (1977) and ISRM (1978).

Our study site extends above the federal road B 305 between Unterjettenberg and Schwarzbachwacht in the Bavarian Alps. The terrain can be characterized as a steep and densely forested limestone slope with two extensive cliffs in two altitude levels in the middle and upper slope, providing a majority of the rock fall material.

In this contribution we focus on our analysis and the characterization of the source area. We aim to demonstrate how quantitative and reproducible geological input parameters can be determined by addressing the following key questions:

- How can we optimize our process understanding by collecting enhanced data, for example shear parameters, considering the source areas?
- How can we achieve an accurate and reproducible parameter reconnaissance for the detachment processes?
- How can the approaches of BARTON & CHOUBEY (1977) be better implemented in rock fall modeling?

## 2 Methodology

### 2.1 Fieldwork

To assume block sizes in a realistic way, we performed a detailed mapping of the release areas in the field. The extension of the cliffs was mapped combining the information of hillshades generated of a 1m-DEM and extensive field work. The orientation of the rock cliffs was interpolated over the slopes extension. Approximately 100 joint orientations were taken to characterize the different joint systems.

Further analysis focused on a key object, a single block subjected to planar failure, where it was possible to directly access the detachment surface (Fig. 1).This included measurements of fracture roughness, joint compressive strength and a mapping of rock bridges (BARTON & CHOUBEY 1977, ISRM 1978).

The joint compressive strength was recorded in situ at the detachment surface as well as at the rock bridges in the "detachment cave" using the Schmidt Hammer $N_2$-Type (BARTON & CHOUBEY 1977, SCHMIDT 1957, WOSZIDLO 1989).

### 2.2 Assessment of field data

The evaluation of the structural data was accomplished using the Schmidt-Net as well as the program DIPS 5.1 (Rocscience). We performed an analysis of the discontinuity pattern as well as a kinematic analysis with regard to the mechanism of failure (MARKLAND 1972, TALOBRE 1957).

A map of the release areas was produced for rock fall modeling (DORREN 2010) using the software ArcGIS (ESRI).

*Fig. 1: Block at the release area, a typical example for planar failure. The volume is about 400 $m^3$.*

## 3 Results

### 3.1 Fieldwork and data analysis

Two primary source areas can be located at the project site. One cliff can be located approximately 300 m, and the other one 600 m in height above the federal road B 305. Both cliffs consist of Limestone belonging to the Dachstein-Formation, which can be characterized as a Reef-Debris-Limestone in this region. Beside the two main cliffs there are several small rock faces which can also be considered as release areas.

Based on the results of our mapping, the kinematic analysis indicates that two mechanisms of failure can occur at the limestone cliffs. Fig. 2 illustrates the discontinuity pattern of the source area. The intersection of the planes of K1 and K2 indicates that a wedge failure could be assumed in relation to the rock face. The light grey area in Fig. 3 refers to the critical discontinuity intersections associated with wedge failure. The dark grey section on the right side of Fig. 3 encloses the poles of critical joint sets for planar failure. For each analysis of failure a minimum friction angle between 30° and 35° was assumed for the limestone (CRUDEN & HU 1988, HECKMANN et al. 2012, HOEK et al. 1998). According to Fig. 3 joint set K1, is exposed to planar failure whereas the intersection of Joint Set K1/K2 is exposed to wedge failure in relation to the rock face.

Our kinematic analysis is in agreement with our field observations, since the fracture surface of the observed block (planar failure) belongs to joint set K1.

The map of Fig. 4 shows a plan view on the detachment surface underneath the block. The upper limit of the cave is defined by rock bridges, connecting the block with the rock mass. The base consists of loosened limestone blocks (blocky rock mass).

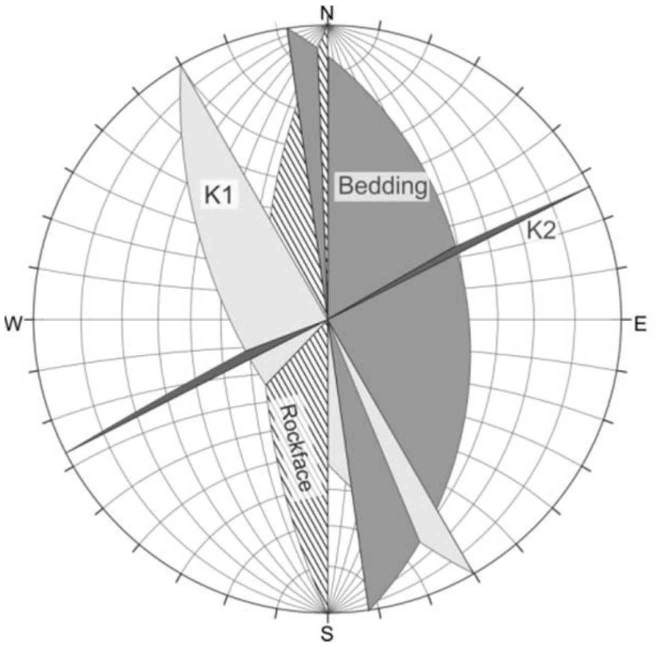

*Fig. 2: Joint pattern of the discontinuity sets. The intersection of joint set K1/K2 could be critical for wedge failure. The joint set K1 shows potential for planar failure. Both cases can be varified in the field.*

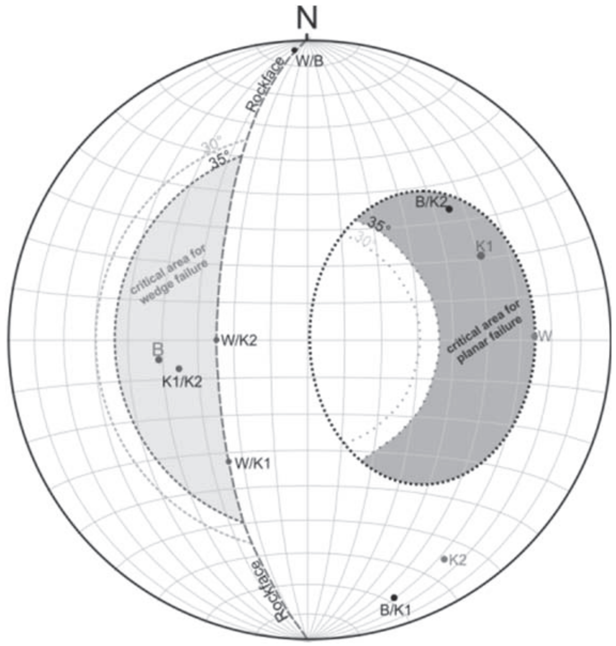

*Fig. 3: Kinematic analysis of the joint sets. The intersection of joint set K1/K2 shows potential for wedge failure. The joint set K1 shows potential for planar failure. Both cases can be varified in the field..*

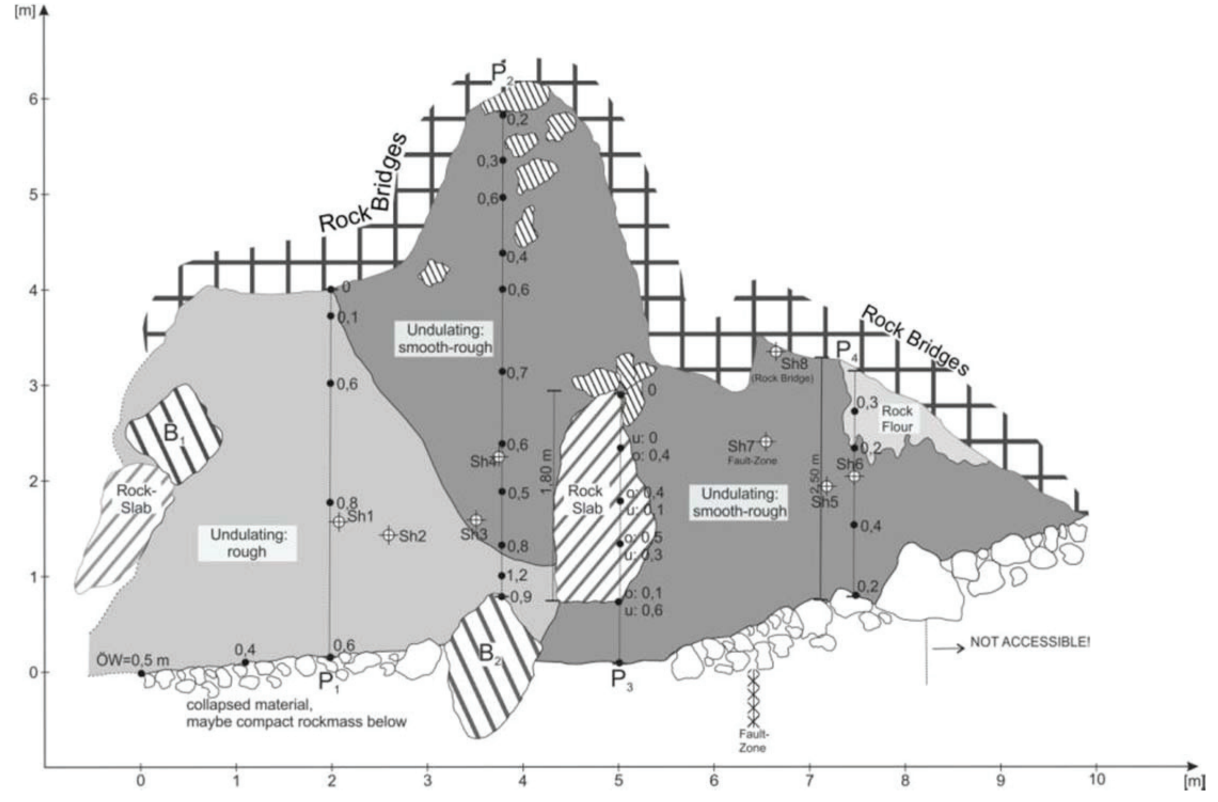

*Fig. 4: Map of the detachment surface of the observed block. The colour indicates the roughness referring to ISRM (1978), the black lines represent profiles through the cave labeled with the opening width in m. The light grey field on the right marks an area where sheared material (rock flour) was sampled.*

The cave-dimensions are approximately 10.5 m across slope up to 6 m up slope. The rear 2 m of the cave is not accessible, since the height as well as the opening width of the cave is decreasing. The shaded polygons represent limestone blocks or slabs which are locked in the detachment zone. The map of the detachment surface (Fig. 4) can be divided in two sections based on fracture roughness. The north part (left part in Fig. 4) can be characterized by its undulating rough fractures. The south part (right part in Fig. 4) can be described as undulating (ISRM 1978), but less rough than the left section. The black lines ($P_{1-4}$) represent recorded profile through the cave labeled with the opening width. Our measurements along the profiles indicate that the opening width varies between 0.1 and 0.5 m in the upper part and 0.5 and 1.2 m in the base-part of the cave. The light grey field in the right part of the cave marks an area where fine grained sheared material is dispersed on the detachment surface, indicating an active cracking of rock bridges related to shearing failure.

Joint compressive strength tests were accomplished in situ on the detachment surface of the observed block. The test-positions are marked as $Sh_{1-7}$ in Fig. 4. We performed the tests on the detachment surface of the rock mass, since the fracture surface underneath the block was hard to access for accomplishing the tests.

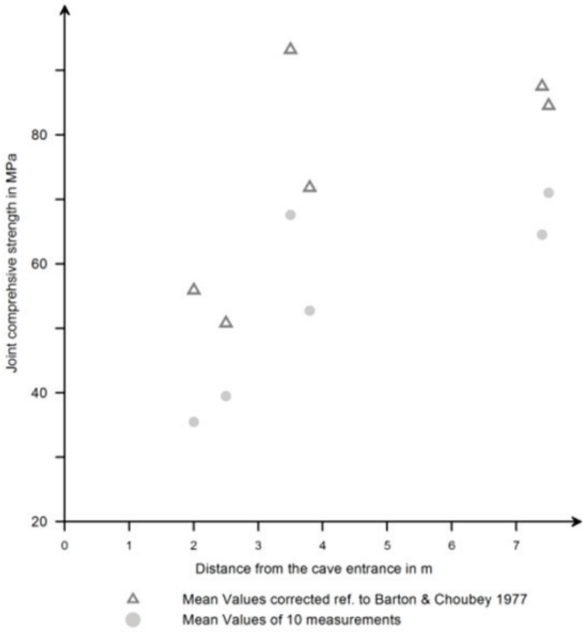

*Fig. 5: Plot of the joint compressive strength (JCS) and the distance from the cave entrance. The dark grey triangles show the mean vauel out of 10 single measurements. The light grey points represent the mean values of ten single tests corrected according to* B*ARTON* & C*OUBEY (1977).*

In Fig. 5 the values of the joint compressive strength (JCS) are plotted in relation to the distance from the "cave" entrance, meaning the location where we entered the detachment zone underneath the block. We plotted two sets of values: the dark grey triangles represent the mean values of each ten single-tests, corrected referring to BARTON & CHOUBEY (1977). This correction requires that the 5 lowermost values have to be eliminated, implying that only the best 5 out of 10 values are plotted. The light grey points represent mean values of all 10 single measurements each. Both value-series show an increasing JCS with increasing distance from the "cave" entrance.In a second step we analyzed the relation between the surface conditions and the joint compressive strength (JCS) (Fig. 6). The Box-Whisker Plot in Fig. 6 indicates a trend of increasing joint compressive strength by decreasing fracture roughness. The right section of the plot takes the rock bridges as an extra class into account, demonstrating that the JCS of the rock bridges is significantly lower than the JCS-values of the detachment surface. The plot of the test series $SH_3$ and $SH_6$ shows a wide dispersion, which is indicated by the length of the whiskers.

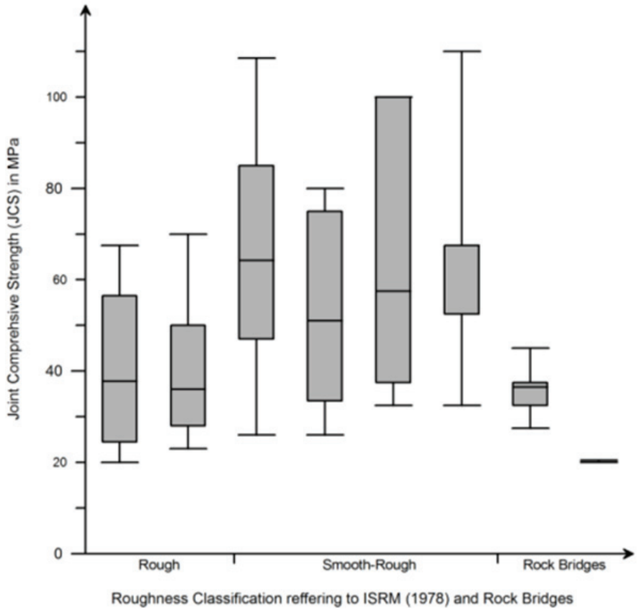

*Fig. 6: Joint compressive strength (JCS) plotted against the fracture roughness (ISRM 1978), including the rockbridges as an extra class. The mean values of the JCS are insreasing with decreasing roughness. The JCS (23 to 38 MPa) of the rock bridges is significantly low.*

For the evaluation of this Box-Whisker-Plot, we included all ten single values of each test series, meaning we were not performing a data correction referring to BARTON & CHOUBEY (1977). Since we intend to consider the detachment surface of the rock mass in in-situ, we decided to take all single values of every test series into account.

## 4 Discussion

Based on data presented in Fig. 5 we suggest that the discontinuity is more weathered in the region around the cave-entrance than in the inner part of the detachment cave. We consider that it is possible that the discontinuity opened in a direction from the entrance to the inner part of the cave. A further explanation for the lower JCS-values at the region around the cave-entrance could be the varying roughness. With increasing fracture roughness the joint compressive strength could decrease, since the front of the Schmidt-Hammer is shaped in a convex way and the diameter of the hammer head is smaller than the changes in fracture roughness. The third test series ($Sh_3$) was performed on a very smooth sampling plane so that the mean values show a high joint compressive strength in this case compared to the other results.

The Box-Whisker-Plot in Fig. 6 indicates the same trend, considering the mean values, as could be derived out of Fig. 5. The clear decrease in the JCS (23 – 35 MPa) considering the rock bridges can provide certain evidence that the rock mass must be loosened up underneath the block. Continuing this interpretation it could be an indication for active cracking of the rock bridges.

## 5 Conclusion

A detailed mapping of rockfall source areas provides information on both mechanisms of failure and the potential of failure in relation to the slope orientation. For that reason a consideration of the discontinuity sets in relation to the slope orientation is necessary. Identifying the critical mechanism of failure, we can improve the input data for rock fall modeling. We can enhance the accuracy of the rockfall analysis at areas with a high disposition for rock fall events. The information provided by collecting accurate data about the detachment process can improve our understanding of rockfall processes and allow more accurate simulation.

Considering the key object, the block subject to planar failure, we performed a recording of the shear parameters. Since we had the unique occasion to directly enter a detachment zone it was possible to demonstrate that the approaches of BARTON & CHOUBEY (1977) have still substantial relevance considering the detachment process, at least in case of planar failure. The results obtained from the mapping of the detachment zone provide certain evidence that the cracking of rock bridges has an amplified influence on the detachment process.

The results of the JCS tests demonstrate that the Schmidt-Hammer could be used for in situ tests on the detachment surface, since it is not possible to provide the in situ conditions in real scale in the laboratory.

However we conclude that a detailed and reproducible analysis of the source area, meaning the recording of joint orientations as well as the shear parameters, is advisable as an amendment for rock fall modeling. Hereby the approaches of BARTON & CHOUBEY (1977) could conduce as a basis to further considerations in terms of detachment processes in a certain rock mass.

## 6 Outreach

One of the next tasks would be to try to quantify the content of active rock bridges by performing an all-out analysis of the shear parameters referring to BARTON & CHOUBEY (1977), taking the assumption into account, that the rock bridges represent a substantial part of the cohesion.

Since up to now the roughness was determined by classification of the JRC (BARTON & CHOUBEY 1977), we plan to quantify the roughness by using a Barton-Comb.

In August 2012 we installed 4 Extensometers (Fissurometers) connected to a data logger at the observed block, to get information about the displacement rates. Until spring 2013 we plan to evaluate the displacement data form the winter months.

Since we suppose that the detailed analysis of the source area has an important effect on the run-out analysis in terms of block sizes, it will be interesting to check this fact by providing the next set of input parameters. We intend to prepare two parameter sets: one set including the enhanced information about the cubature and the other one estimating the block sizes by deposit and break-out material.

## Literature

BARTON, N. & CHOUBEY, V.(1977): The Shear Strength of Rock Joints in Theory and Practice.- Rock Mechanics, **10**: 1-54.

CRUDEN, D.M. & HU, X. Q. (1988): Basic friction angles of carbonate rocks from Kananaskis country , Canada.- Bulletin of the International Association of Engineering Geology, **38**: 55-59.

DORREN, L. (2010): Rocky for 3D revealed - Description of the complete 3D rockfall model. Association ecorisQ.

GEOTEST AG (2006): Steinschlag-Modellierung ROFMOD 4.1. Benutzerhandbuch, Zollikofen.

EVANS, S. G. & HUNGR, O. (1993): The assessment of rockfall hazard at the base of talus alopes.- Can. Geotech. J., **Vol. 30**: 620-636.

HECKMANN, T., BIMÖSE, M., KRAUTBLATTER, M., HAAS, F., BECHT, M. & MORCHE, D. (2012): From Geotechnical Analysis to quantification and modelling using LiDAR Data: a study on rockfall in the Reintal catchment, Bavarian Alps, Germany.- Earth Surf. Process. Landforms, **37**: 119-133.

HOEK, E., MARINOS, P. & BENISSI, M. (1998): Applicability of the geological strength index (GSI) for very weak and sheard rock masses. The case of the Athens Schist Formation.- Bull. Eng. Geol. Env., **57**: 151-160.

ISRM - INTERNATIONAL SOCIETY FOR ROCK MECHANICS (1978c): Suggested methods for the quantitative description of discontinuities in rock masses. - Commission on Standardization of Laboratory and Field Tests.- Int. J. Rock Mech. Min. Sci. & Geomech. Abstr., **15**, No. 4: 319-368.

MARKLAND, J. T. (1972): A Useful Technique for Estimating the Stability of Rockslopes when the Rigid Wedge Sliding Type of Failure is Expected. Imperial College, Rock Mech. Research Report, **No. 19**: 10 p.

MÖLK, M. P. (2008): Rockfall Rating Systems: Is there a comprehensive method for hazard zoning in populated areas?- Interpraevent 2008-Conference Proceedings: 2, 207–218.

SCHMIDT, E. (1957): Betonprüfhammer: Gebrauchsanweisung. – PROCEQ S.A., Zürich.

SCHWEIGL, J., FERRETTI, C. & NÖSSING, L.(2003): Geotechnical charakterization and rockfall simulation of a slope: a practical case study from South Tyrol (Italy).- Engineering Geology, **67**: 281–296.

TALOBRE, J. (1957): La Méchanique des roches. S. 39-44, Paris (Dunop).

WOSZIDLO, H. (1989): Untersuchungen an Festgesteinen mit dem Prallhammer nach Schmidt. -. Nat. Tag. Ing-Geol., Bensheim, Ber. **7**: 287-294.